Eye mask measurement accuracy

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Problem statements:

1. Eye mask margin measurements can be misleading and less than accurate

2. Eye measurement procedure is not fully specified in reference standards

3. Seeking correlation between TDP and other measurement methods

This is a general analysis, not specific to any bit rate

Eye mask addresses high probability impairments (“deterministic”); various noise effects can give misleading results
Mask measurement: Scope and Tx noises means measuring for longer makes apparent eye smaller.

Tails of distributions do not affect link performance: they are drowned by link’s Rx noise and jitter (noises combine as sum of squares).
Noises combine as sum of squares:

**Typical example for 10G Ethernet measurement**

Probability distribution (Tx under test) combines with probability distribution (scope) to determine mask hit rate

(Measurement technique determines scatter in measurement)

**Measurement:**

\[(\text{Tx noise})^2 + (\text{scope noise})^2 = (\text{measurement total noise})^2\]

*example:* \[0.03^2 + 0.02^2 = 0.036^2\]

**Target use:**

\[(\text{Tx noise})^2 + (\text{Rx noise})^2 = (\text{system total noise})^2\]

*example:* \[0.03^2 + 0.139^2 = 0.142^2\]

Drowned by link Rx, not important at this level

And see backup
Scope and Tx noises means measuring for longer makes apparent eye smaller:

Distributions of both DUT and instrument contribute to mask hits

Jitter

Noise

[Diagram showing eye mask measurement accuracy]
Real receiver noise is much greater than scope or DUT noise.

In actual use, tails of Tx distributions are drowned by link’s Rx noise and jitter.

Example Signal to noise ratios:
- Rx noise: 7
- Scope noise: e.g. ~50 to 100
- Tx noise: ~30? is enough
Number of samples

Even modern sampling scopes miss most of the signal

**e.g. 40 ksamples/ s**

as slide 5

Good for finding high probability effects and for diagnostic analysis

**Actual system or TDP test takes 125,000 to 10,000,000 ksamples/ s**

as slide 6

Do not recommend using eye mask on scope (DCA) to characterise low probabilities:
TDP spec addresses these
Theoretical analysis of relation between actual transmitter penalty and observed mask margin: method

1. Calculate relation between transmitter penalty (TP) and mask margin (MM) assuming no noise anywhere:

\[ TP = 10 \log_{10}(1/H), \quad MM = (H-M)/(1-M) \]
where \( H \) is height of inner eye and \( M \) is height of mask*

2. Extend calculation to allow for penalty of Tx noise

3. Extend calculation to include scope noise

4. Find position in tail of distribution representing 0 hits

5. Find likely scatter around that point

6. Graph out likely range of apparent mask margin vs. actual transmitter penalty for a family of transmitters from good to bad

* See slide 5 Analysis assumes \( \alpha = 0.5 \)
Theoretical analysis of relation between actual transmitter penalty and observed mask margin

Basing mask margin on zero hits may produce widely varying results!

Distribution of measurements (same scope and DUT)

About 0.7 dB uncertainty

Or about 20% mask margin uncertainty

Assuming typical measurement procedure

Basing mask margin on zero hits may produce widely varying results!
Theoretical analysis of relation between actual transmitter penalty and observed mask margin

Basing mask margin on zero hits may produce widely varying results!

Distribution of measurements (same scope and DUT) or about 20% mask margin uncertainty

About 0.7 dB uncertainty

Scatter range shown is ±2.5 standard deviations (99% of measurements would fall in this range).

Our experience is that the standard deviation of repeated measurements of mask margin on same DUT is about 3%, giving ~15% range.

This is more to do with the measurement than the DUT.

New lower noise scope plug-in helps.
Industry standard: 200 waveforms, no hits

Low accuracy of industry standard mask margin measurement: comparing different DUTs

Now showing transmitters with different types of impairment: deterministic and random. 3 examples in 3 colours.
Can we get better accuracy with more waveforms?

No

10,000 waveforms 0 hits would give very pessimistic and irreproducible results: comparing different DUTs

- All curves 10000 waveforms, 0 hits, with measurement scatter
- 1. Low noise transmitter
- 2. Intermediate
- 25% of penalty being noise
- 3. Noisy transmitter
- 50% of penalty being noise

Still widely varying; also can be pessimistic

Note some of these curves are more pessimistic than previous page (“200 waveforms”) by up to 10%
Intermediate position still suffers from over-measured noise and scattered results.

Some of these curves are more pessimistic than “200 waveforms” by up to 5%.
1000 waveforms 10 hits would give much more consistent and representative results

Proposal for best accuracy

All curves 1000 waveforms, 10 hits, with measurement scatter

1. Low noise transmitter

2. Intermediate

3. Noisy transmitter

Would expect most transmitters to be between red and green

Much better! Better grouping, less scatter

Hit limit scales with sample size for stable reading

This is 10 hits in 225500 samples/UI or ~1 hit per 2.10^4 samples/UI

0% 20% 40% 60% 80% 100%

-20% 0% 20% 40% 60% 80% 100%

0 1 2 3

Actual Transmitter penalty (dB)

Apparent Mask Margin

1000 waveforms 10 hits would give much more consistent and representative results.
Numbers of waveforms, number of hits

Need a reasonable number of DCA “waveforms” to get samples from all likely patterns

e.g. 10 sweeps would be too few

We believe “200 waveforms” is industry baseline, and different companies add margin to this in different ways

This number is widely assumed but we can’t find it written down in any standard

Criterion of 0 hits gives poor reproducibility, for any number of waveforms

Increasing the number of samples with 0 hits over-measures random effects and may be affected by scope noise

And see backup
Summary

Mask margin based on very few or zero hits can be misleading and generate unrepeateable results

Increasing the number of waveforms reduces the apparent mask margin, does not make the measurement much more repeatable and overmeasures transmitter and scope noise

Increasing the number of waveforms AND allowing a finite number of hits improves both measurement repeatability and relevance

Need to define a set proportion of hits/sample/UI

Too low a proportion: large measurement errors and unrepresentative (too pessimistic)

Too high a proportion: too lenient in some cases

1 in 2.10^-4 hits/sample/UI: about right

10 sided masks in Ethernet standards should be adequate; no need to add more margin except for ageing

TDP test is the “gold standard”, not the mask

TDP measurement is designed to be representative of actual performance
SONET

Mask margin measurements with 4 sided masks (OC-48, OC-192) are expected to be less reproducible unless care is taken, because the convolution of a slanting trajectory of the waveform against the rectangular mask gives a “fat tailed distribution”

Relation of waveforms to samples

I have assumed 451 samples across scope screen and 2 UI/ screen (20 ps/ div). I believe that older scopes contemporary with OFSTP-4 would have been in this ballpark.

“Number of waveforms” means number of samples x samples/ screen

Thus “200 waveforms” gives 90200 samples in all, of which 45100 are in the eye compared with the mask.

Modern scopes have controllable samples/ screen up to 4096.

Of the samples in the right UI (where the mask is), only 1/ 4 relate to 010 and 101 patterns which determine the penalty.

Of these, only a fraction come anywhere near the mask (mask is 0.5 UI long anyway).

Signal and noise levels

signal to noise ratio = Q = (1/ 2 eye height)/ (RMS noise)